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VARIAN ASSOCIATES (A)

The Redesign of a Liquid Nitrogen Container

Historical Background

Paul Hait, an engineer with Varian Associates, Palo Alto, California, was assigned the task of redesigning an existing liquid nitrogen container for use on a cold trap (VacSorb) vacuum pumping system

The Problem

Paul Hait, an engineer in the Vacuum Products Division of Varian Associates, was charged with the task of redesigning an existing polystyrene container for liquid nitrogen which is utilized with a VacSorb vacuum pumping system. The problem-plagued container had been analyzed periodically since 1961 by Varian engineers, but probably due to its low cost (compared to the equipment it was used with) the container and its problems were relegated to a low position on a priority list of problems. However, an increasing number of customer complaints had pushed the container to the top of the list. The chief complaints were that the container leaked nitrogen through cracks in the polystyrene beads and that the aluminum mounting ring would separate from its embedded position in the polystyrene wall The warranty replacement costs to Varian Associates were climbing too high to be ignored. Thus, in the spring of 1963 Paul Hait was assigned the task of resolving this problem. However, to fully appreciate Paul's role in the redesign of the container, some background information and the events preceding Paul's assignment will be presented first.

Prepared in the 1966 Summer Case Methods Workshop at Stanford University with support from the National Science Foundation
Written by William S. Chalk, University of Washington, Ivan A. Shirk, Gonzaga University, and Robert B. Thornhill, Wayne State University

The authors wish to express their appreciation to Varian Associates for their wholehearted cooperation in the writing of this case. Thanks are also due Peter Z. Bulkeley and Karl H. Vesper of the Design Division, Mechanical Engineering Department, at Stanford, for much valuable assistance.

Varian Associates

Varian Associates designs and manufactures such sophisticated devices as mass spectrometers, ultra-high vacuum pumps, and solid state devices for use in industry and scientific research. It is an international company with facilities located in the United States and several European countries. The company was founded in 1948 by the Varian brothers and a group of their colleagues in a rented garage-shaped building in San Carlos, California, with capital assets of $22,000. Annual sales have increased from almost $60,000 for the first year of operation to an estimated $140 million for 1966.

Varian is divided into three main divisions as follows:

(a) "Electron tube and device group" - whose major products are microwave tubes, solid state electronic devices and microwave components.

(b) "Instrument group" - whose major products are spectrometers, gas chromatographs, and superconducting magnets.

(c) "Equipment group" - which is divided into the Radiation Division and the Vacuum Products Division.[1]

One of the items produced by the Vacuum Products Division is the VacSorb Pump[2] which is essentially a cold trap. The trap contains an activated metallic solid to which gaseous molecules readily adhere when cooled by liquid nitrogen. The liquid nitrogen surrounding the cold trap is contained in a vat or flask to which more may be added from time to time as the supply is depleted through evaporation.

The Need for the Container

The need for a liquid nitrogen container came as a direct consequence of the development of the VacSorb Pump. Liquid nitrogen was an excellent element for a cold trap, but you needed some type of properly insulated container to hold it.

Originally Varian[3] was using Hoffman glass dewars[4] which were very much like thermos containers. The Hoffman dewars were bulky, difficult to work with and required some type of auxiliary stand to hold them. As a consequence, they could not be hung directly off of a VacSorb Pump.

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[1] See Exhibits 1 through 3.

[2] See Exhibit 4.

[3] Varian Associates - Vacuum Products Division.

[4] Dewar - A Cryogenic Container.

The Hoffman dewar had still other disadvantages; for example, if it were knocked off of its auxiliary support stand and hit the floor, it would shatter. It was also quite heavy. However, thermally, it did give good performance and liquid nitrogen placed in it would last for a long period of time (seven to nine hours). But for most VacSorb Pumping operations there was really no need to have the liquid nitrogen in the dewar that long. Also it took a greater amount of liquid nitrogen to initially chill or pre-chill a Hoffman dewar than, say, a dewar made out of plastic, simply because of the thermal characteristics of the glass.

The First Polystyrene Dewar

Varian engineers felt that the Hoffman dewar was not really satisfactory and should be replaced. However, no one was really sure as to what to replace it with.

One evening, on the way home from work, Pat Dorney[5], the Marketing Manager of the Vacuum Products Division, stopped to pick up a bottle of good California champagne. As advertising, the store where he purchased the champagne included a free cooling bucket with his purchase. This cooling bucket was nothing more than a plastic type container that would hold ice for cooling say, a bottle of champagne. Later that evening Pat Dorney thought that maybe you could use this type of bucket (or something similar to it) as a container for liquid nitrogen. He brought the cooling bucket to work the next day, filled it with liquid nitrogen and found that it held the nitrogen quite well. This immediately led him to believe that a plastic type container, possibly made out of polystyrene, would made an excellent liquid nitrogen dewar for the VacSorb Pump. He discussed the idea with some of the engineering group leaders in the Vacuum Products Division, but at the time none of them seemed to think much of it.

All of this took place in April of 1960 and it wasn't until almost a year later that Varian engineers decided that Pat Dorney's idea had real merit. At this time they decided to begin development of a polystyrene dewar that would serve as both an insulation medium and structural container for liquid nitrogen. This type of dewar had some definite advantages over the Hoffman variety. Its pre-chilled time was short, it was light weight, it could be dropped on the floor without breaking, and it would cost less to produce. The Hoffman dewar sold for between $65 and $70, whereas a polystyrene dewar could probably be manufactured to sell for around $25. Thus, it would be a much more economical item to use with a VacSorb Pump.

Bill Wheeler, the engineer in charge of the Components Group in the Vacuum Products Division was given the responsibility for developing such a dewar. He came up with an initial design for a molded polystyrene dewar that was 12" long with a 6" inside diameter and a 7 1/2" outside diameter. Around the top of the dewar was a notched aluminum support ring used for hanging the dewar to the VacSorb Pump. This ring was to be partially imbedded in the styrene[6] and permanently affixed in this position (Exhibit 5).

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[5] Mr. Dorney is now Vice President of the Vacuum Products Division.

[6] Styrene will be used hereafter as short for polystyrene.

A vendor in Santa Clara was paid $1250 to make a mold that could be used to fabricate this dewar. This first mold was of the top feed variety. Unfortunately, this vendor's factory burned down and the mold, which Varian had in their possession was then shifted to a new vendor, Pelafoam Corporation in Richmond, California. Pelafoam had a different way of fabricating the dewars, but they could use the same mold with one exception; they could not fill the mold from the top. What they had to do was fill it from the side. So a new penetration was made in the side of the mold and the old filler hole in the top of the mold was plugged up. The material used in the molding process was styrene type beads ranging from .015" to .020" in diameter. See Exhibit 6 for an illustration of the mold and a description of the molding process.

In his early development work on the dewar Bill Wheeler noted that different styrene bead densities and sizes would give various results. Large beads (low density) would not bond well enough to each other and thus the dewar would leak. Small beads gave too high a density to the dewar, and as soon as the liquid nitrogen was poured into it, the dewar would fracture. A low density dewar was preferred; however, to prevent leaking, he thought that it had to be constructed with the proper combination of large and small diameter beads. Kopper Chemical Company, one of the vendors from whom the beads were purchased suggested that about a three lb/ft^3 bead density should be satisfactory. However, there was very poor quality control on this density in the early buckets. It just wasn't realized that bead density was such a critical factor.

Bill Wheeler had the mold brought to Varian for examination. It was immediately obvious that the injection holes for steam in the mold itself caused a bead distribution problem with respect to the exterior sufface of the dewar. You could see little indentations and protrusions in this surface which detracted from the appearance of the dewar. These surface irregularities had to be sanded off and this added an extra production step that was not desirable.

There was also a problem encountered in the surface finish of the dewar. When they were received by Varian, the dewars were white in color and thus were very susceptable to any type of dirt and grease stains. Small dents were also unsightly. This was not a desirable thing and so to minimize the condition the dewars were painted gray. The initial paint that was used sometimes etched the styrene beads and caused a pitted surface effect that was undesirable. This led to using a latex type paint which would not dissolve or deteriorate the bonded styrene beads. However, the first coat of latex paint flowed into any tiny unbonded sections of the beads and the resultant surface finish had a pitted effect where this flow had occurred. Thus, a second and third coat of latex paint was required to give the dewar a good quality surface finish. Then the company name (Varian Associates) was spray painted on the outside surface of the dewar (Exhibit 7), and it was ready to be sold. This was in late 1961, and the dewar was placed on the market in early 1962.

Problems with the First Styrene Dewar

All Varian Products have a one year warranty and several months after the styrene dewar was marketed, customer complaints began to roll in. The main complaint involved dewar cracking and leaking when used with liquid nitrogen (Exhibits 8(a) and 8(b)). Many of the cracks that occurred in the styrene were in the vicinity of the aluminum top support ring. Part of the ring was exposed around the entire circumference of the dewar. When the liquid nitrogen would come in contact with this ring, the differential expansion between the styrene and the aluminum would cause a rather severe thermal shock. This shock would be most prevalent over the area of contact between the aluminum ring, the styrene, and the liquid nitrogen. However, it did to some extent manifest itself around the entire contact area of the ring and styrene. This type of cracking was the result of a thermal shock condition. There was also the rather arbitrary cracking of the dewar in other regions and no one was able to explain as to why this was happening (Exhibit 9).

At this time (May of 1962) Bill Wheeler was deeply involved in other work at Varian and Maurice Carlson, a junior engineer in the Components Group, was given the responsibility of correcting the field difficulties that some customers encountered when using the liquid nitrogen container. Maurice began by investigating the formulation of the bonded styrene beads and the problem of bead density. He more or less repeated the same work that had been done by Bill Wheeler. But, he did investigate in more detail the determination of an optimum bead density for the dewar. He arrived at what he believed to be an optimum density value (2.7 lbs/ft^3) and felt that this was the solution to the cracking and leaking problem However, dewars fabricated using this density specification didn't work any better than the ones Bill Wheeler had developed.

At this point in time, September of 1962, no one knew exactly what to do. Since the dewar was sort of a low priority item, and since it sold for only $25, it was placed into the hands of production engineering. They inherited the dewar through a kind of "passing the buck" decision. So having passed the buck over to production, it then became John Cape's responsibility to try to determine why the dewar was cracking and what to do about the cracking and resultant leaks.

John Cape was not the right man to do this job. He was a good production engineer and in charge of the degreasing and cleaning facilities at Varian However, he was not oriented to the problem in such a way that he could literally dive right in and do a good, thorough analysis on the dewar.

All during this time no attempt was made to make any person-to-person contact with the Pelafoam Corporation who was fabricating the dewar. The drawings and molding specifications were simply sent to the Purchasing Department and they would forward this information along with a purchase order to Pelafoam. The molded dewars would come back from Pelafoam and if they didn't perform satisfactorily the whole process would be repeated with some changes in the molding specification. It seemed that all the solutions that were being proposed were in-house developed ones, and more or less speculations and guesses.

John Cape did not really have sufficient time to study the problem and propose a solution. In October of 1962 Stan Swaidek, Production Engineering Manager of the Vacuum Products Division took over the dewar problem

It was about at this time that Paul Hait started to work for Varian. One of the first things he was exposed to during a tour of the production facilities was the problem that the company was having with a liquid nitrogen container He observed numerous attempts by Stan Swaidek to solve this problem For example, Stan tried coating the outside of the dewar with a thin, plastic coating; he tried making a dewar out of a new material (urethane foam); he tried making a dewar without any support ring on the top; and he tried painting both the inside and the outside of the dewar with special paints which had exceptionally good thermal properties.

In January of 1963 Stan Swaidek stated that he did have a solution to the dewar problem. The solution was to paint the dewar three times on the outside, leave the same aluminum support ring on the top, and make a polyethylene liner which would fit snugly inside the dewar He indicated that these imporovements would increase the cost of the dewar by about fifty cent. A mold was purchased for about $250 to make the polyethylene liners and new dewars were fabricated with Stan Swaidek's proposed changes.

Out of the first production run of new dewars, one was almost immediately used by Paul Hait in a laboratory where he was carrying on some high vacuum experiments. He found that the dewar still was not satisfactory When he poured liquid nitrogen into it, the polyethylene liner almost immediately contracted and the liquid nitrogen flowed around and under it This caused the liner to float and it started rising out of the dewar Now Varian had a telescoping liquid nitrogen dewar that, to say the least, wasn't very practical

It turned out that Stan Swaidek had not performed any meaningful laboratory tests on the polyethylene liner in the dewar before he released it for production Hence, some way of holding the liner in place had to be quickly devised A styrene ring was designed which would fit into the dewar over the top of the liner and hold it in place To hold the ring in place three equally spaced holes were punched in the aluminum support ring and rivets placed in these holes just above the styrene ring This, of course, added extra tooling, labor, and material costs to the total price of the dewar This change was made, and the dewar was marketed in March of 1963 with this and the other changes proposed by Stan Swaidek

In a short time, more customer complaints than ever were coming into Varian The dewars were still cracking with resultant leaks and there were also numerous complaints about excessive wrinkling of the polyethylene liner, making it very difficult to pour liquid nitrogen into the dewar. So the solution proposed by Stan Swaidek had not solved the problem, but only compounded it.

The dewar was still considered to be a rather minor new product item, and no one had fully realized the seriousness of the problem until Paul Hait conducted a search in the Varian Warranty Replacement Group in mid 1963. He found that since the styrene dewar had first been marketed, about a year and a half ago, over 400 of them had been returned because of defects. Since the company sold only about 1000 dewars per year, this was a significant return.

In April of 1963 the Vacuum Products Division had gotten a new manager, Wayne Phillips. When he was given the information as to the number of defective dewars that had been returned, he realized that this problem could have very serious consequences in terms of the entire Vacuum Products Division. If Varian couldn't make a relatively simple $26 item reliable, what might potential customers think about their much more sophisticated and much higher priced vacuum pumping equipment? The dewar had to be converted into a reliable product or taken off the market altogether. This was a decision that Wayne Phillips had to make.

He decided that the Vacuum Products Division should continue to market the dewar and asked Bill Wheeler to take on the job of making it a reliable product. Bill Wheeler felt that an engineer in his group who had a fresh outlook toward the dewar problem should take it over. Paul Hait was given this task.

PART A - CLASS DISCUSSION QUESTIONS

1. What about the general engineering approach in the design of the liquid nitrogen container. Was it satisfactory?

2. What problems were encountered when the styrene dewars were marketed? How were they solved?

3. What about the people involved in this project? How did they approach the design of the dewar?

4. Design a liquid nitrogen container using a material with better thermal and strength properties than bonded polystyrene.

5. Design a liquid nitrogen container approximately the same size as Varian's but using your own specifications.

6. Suppose you were Paul Hait and were given the liquid nitrogen container redesign problem. What would you do?

EXHIBIT 1

CRYOGENICS

Cryogenic engineering deals with very low-temperature processes and techniques associated with temperatures far below those normally encountered in conventional refrigeration engineering. The cryogenic state has been described not as a fixed or definite temperature, but as a realm that begins below -150°C (-238°F). Above this temperature, engineering practices employed in the design of normal refrigeration equipment are generally adequate. Below it, however, the effects and reactions on system materials and components become important design considerations. For example, at cryogenic temperatures the electrical resistance of some materials becomes negligible and the materials are essentially super conductors.

EXHIBIT 2

VACUUM SYSTEMS

Essentially, a vacuum system is a tool, whether it is used to simulate an outer space environment or in connection with a specific welding technique. For best performance, the vacuum system designer must be familiar with the characteristics of the process for which the system is to be used, and the user must be aware of the capabilities and limitations of the system.

The concept of pressure and its measurement is essential to all vacuum discussions. The basic method of measuring pressure is to balance a weight against an area exposed to the medium to be measured. In high-vacuum systems the weight is usually a column of mercury whose height is used as a measure of the vacuum.

Vacuums have traditionally been measured in millimeters of mercury. However, a new unit, the torr, is gaining acceptance. The torr is defined as 1/760 of a standard atmosphere. Another commonly used pressure unit is the micron, which equals 10^{-3} torr.

Such terms as low vacuum, high vacuum, and ultra-high vacuum are commonly used to denote various vacuum ranges. Exact boundaries between these ranges are somewhat arbitrary. However, a commonly used terminology is to consider everything below 10^{-9} torr as an ultrahigh vacuum, from 10^{-9} to 10^{-6} torr as a very high vacuum, from 10^{-6} to 10^{-3} torr as a high vacuum, and from 10^{-3} torr up to a few millimeters of mercury as a medium vacuum. Values above this are considered to be a low vacuum.

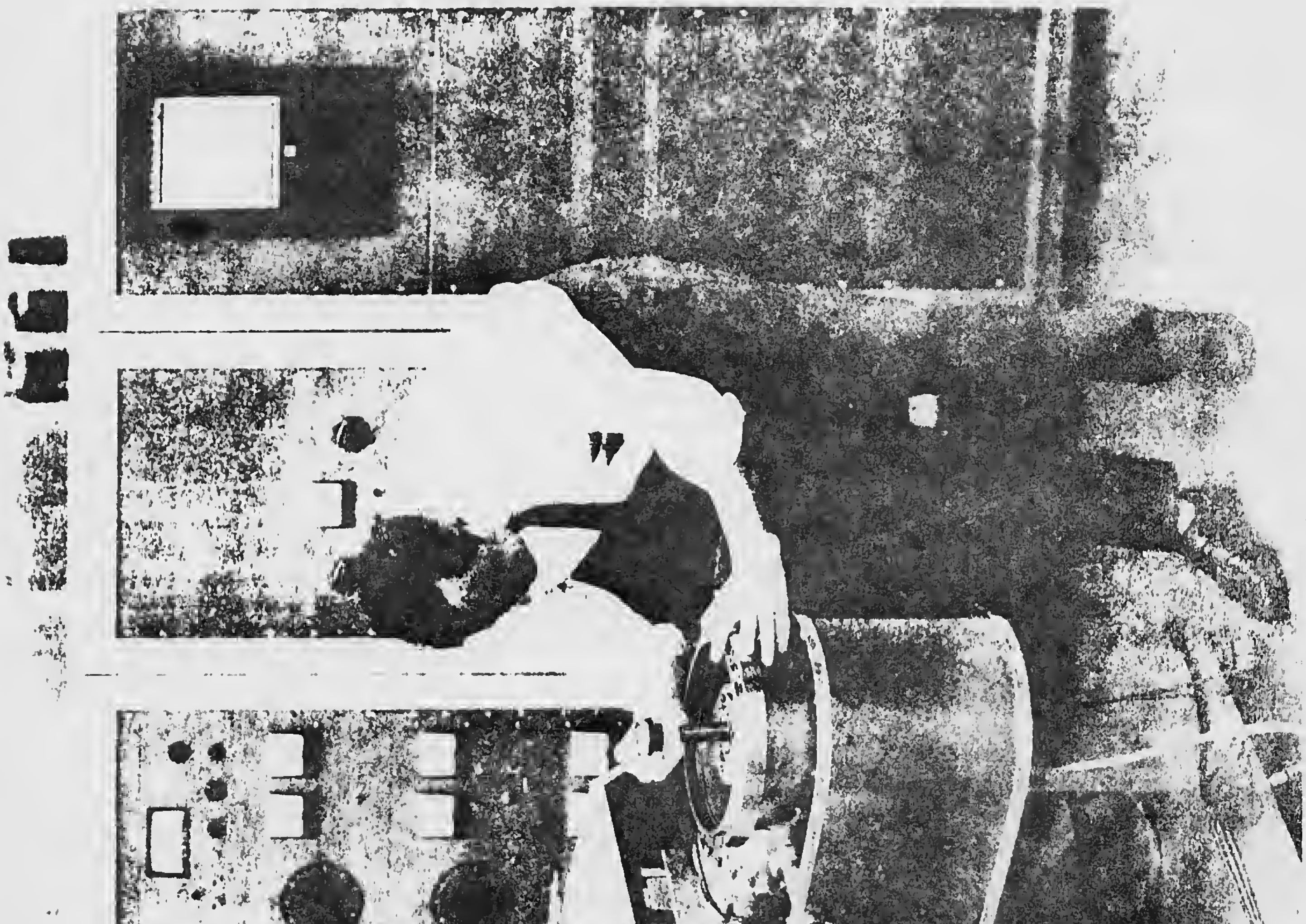


Exhibit 3 A Varian 2500^{0}F vacuum heat treating furnace. (Note the two liquid nitrogen containers)

EXHIBIT 4

ECL 72

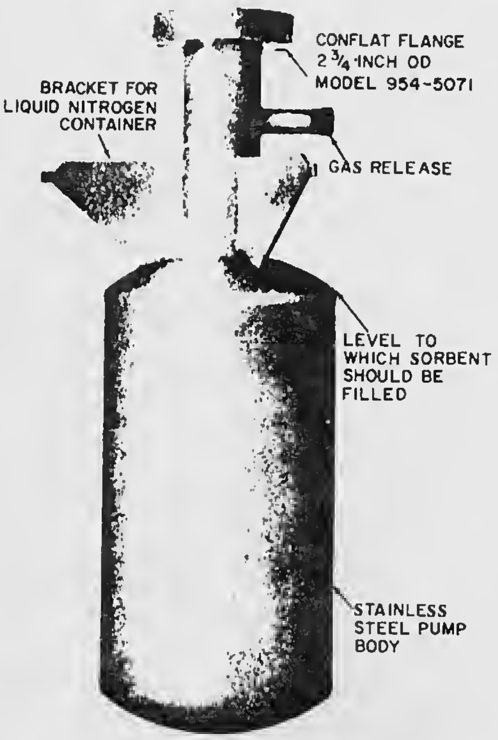
Vacuum Products Division

VARIAN associates

VACSORB® ROUGHING PUMP
MODEL 941-5610

DATA SHEET

It is no longer necessary to sacrifice speed for cleanliness; the new VacSorb Pump has both. The radically improved pumpdown has been achieved through a completely redesigned internal heat transfer element. Externally the new pump is identical and interchangeable with the old, but...the new pump provides superior pumping performance in every respect.



VocSorb PUMP

INTRODUCTION

Varian VacSorb Roughing Pumps are designed to evacuate a leak free vacuum system to pressures of a few millitorr (microns Hg). Under special conditions lower pressures may be achieved. Their main use is to rough pump systems which employ a VacIon® High Vacuum Pump. VacSorb Pumps are the undisputed choice over the conventional oil-seal mechanical pumps when one wishes to maintain system cleanliness during the rough pumping operation.

In addition to being clean, VacSorb Pumps contain no moving parts and use no internal liquids of any kind. Further, they are free of vibration and require no electrical power. These properties give VacSorb Pumps a wide range of applications with vacuum systems that are used for thin film deposition, electron tube processing, mass spectrometers, environmental testing, and a variety of physics experiments.

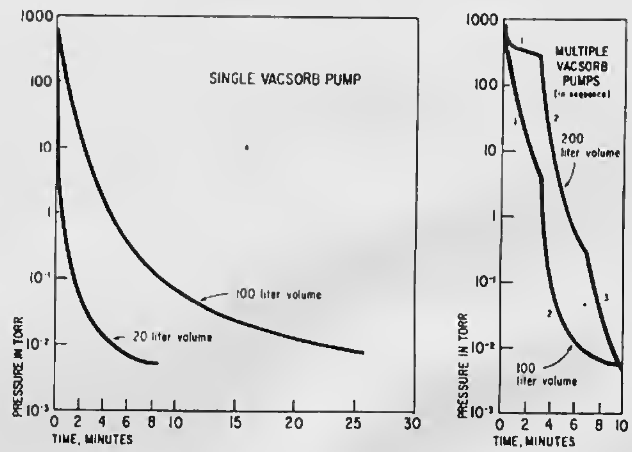
SPECIFICATIONS

1. Pressure Range – Operates from atmospheric pressure to below 1 x 10^{-2} torr (10 millitorr).

2. Pumping Speed – The speed at which a VacSorb Pump operates varies with time, temperature, and volume of gas pumped. The accompanying graphs show typical pumpdown times for single and multiple VacSorb Pumps evacuating various volumes.

3. Pumping Argon – Argon can be pumped in large quantities and at high speeds by VacSorb Pumps. A volume of argon at atmospheric pressure can be quickly pumped down to the starting pressure for a VacIon Pump. The number of VacSorb Pumps required and pumpdown times for argon are similar to those for air or nitrogen. In typical thin film sputtering work a single VacSorb Pump provides clean, fast pumping against a continuous flow of argon for 4 to 8 hours.

PRESSURE vs TIME
(after 10 minute prechill)



VacSorb PUMPS RECOMMENDED	VOLUME RANGE (Liters)	PUMPDOWN TIME* (Minutes)	MAX. VOLUME (Liters)
1	up to 40	up to 10	100
2	40 to 100	5 to 8	230
3	100 to 250	6 to 15	400
4	250 to 400	10 to 25	550
5	400 to 550	15 to 30	600

*After a 10-minute prechill of the VacSorb Pump the pressure will reach 1 x 10^{-2} torr or lower in the time specified.

NOVEMBER 1964

Please address inquiries to: VACUUM PRODUCTS DIVISION, VARIAN ASSOCIATES
611 Hansen Way, Palo Alto, California, U.S.A

European inquiries: VARIAN A.G.,
Baarerstrasse 77, Zug, Switzerland

Exhibit 5 Initial design of the polystyrene dewar

EXHIBIT 6

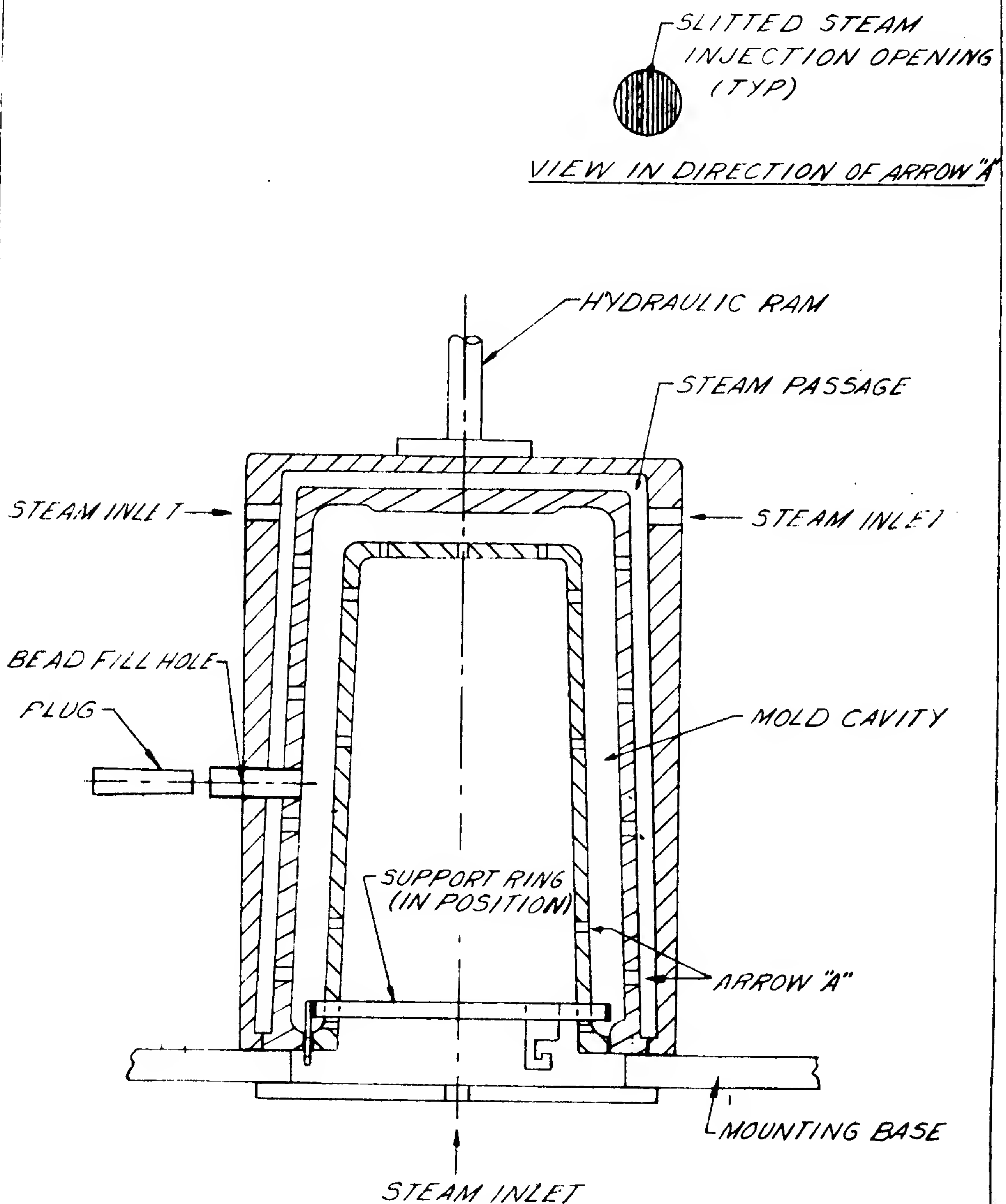
DESCRIPTION OF THE STYRENE MOLDING PROCESS FOR THE LIQUID NITROGEN CONTAINER

The first step in the molding process is to setup the mold as shown in Figure 6-1 and hold it rigidly in place by means of a hydraulic ram. The aluminum support ring is then centered from underneath the mold and clamped in place.

Styrene beads, ranging in size from .015" to .020" are first preheated and then forced into the mold through a hole in its side. A flexible tube fits in the hole opening and the beads are drawn into the mold by means of a vacuum pumping device which feeds beads from a storage drum into the flexible tube and thence into the mold. The reason for preheating is to control the bead density which should be about $3 lb/ft^3$. After the mold is completely filled a plug is placed in the fill hole.

Steam is then introduced into the mold through two openings along the sides and one in the bottom. The steam under a pressure of 19 psi and at a temperature of about 225°F permeates the styrene beads through a series of random spaced openings on the interior and exterior surfaces of the mold. The openings are about 3/8" in diameter and contain a series of narrow slits which are designed in such a way as to allow the steam to enter, but prevent any beads from being forced out during the initial filling process. As the steam penetrates the beads it creates a foaming action which causes the beads to increase slightly in size and be bonded securely to one another to form an integral solid. It takes about ten minutes to complete this foaming action and then the hydraulic ram is released and the mold removed from the completed styrene container. The mold is coated with a special silicone lubricant to prevent the styrene container from adhering to it when the two are separated.

EXHIBIT 6 (FIG 6-1)



MOLD FOR STYRENE DEWAR
FIGURE 6-1

Exhibit 7 Initial polystyrene dewar as it was first marketed (1962)

Exhibit 8(a) Product trouble report for the initial polystyrene dewar

ECL 72

~~VARIAN ASSOCIATES~~ 611 HANSEN WAY — PALO ALTO VACUUM PRODUCTS DIVISION

PRODUCT TROUBLE REPORT

344-0-17 Dec 61

CUSTOMER: Bell Telephone Laboratories	P.O. or S.O. No. (If known): P.O. #5-388094 — DATE: April 19, 1962
	PRODUCT: Liquid Nitrogen Container
ADDRESS: 555 Union Boulevard	MODEL NO. 944-0005
Allentown, Pennsylvania	SERIAL NO.
	CUSTOMER CONTACT: R. Jacobs 215 HE 3-7581 Ext. 632

DESCRIPTION OF FAILURE OR MALFUNCTION OF PRODUCT

Number one dewar cracked thru to outside from the support ring down about 5 inches.

Number two dewar is now starting at more or less the same place but at the moment not all the way thru, but is progressively becoming worse.

Number three dewar has general cracking all around, altho not thru yet.

APPLICATION OF PRODUCT BEFORE OR DURING TIME OF FAILURE

Refrigerating VacSorb pumps on a VI-4 Evaporator.

HAS THE PRODUCT BEEN MISAPPLIED OR MISUSED YES ☐ NO ☒ IF THE ANSWER IS YES, DESCRIBE HOW.

Re the cracking it is the opinion of the customer that the coefficient of expansion of the aluminum ring does not match the styrofoam, thereby setting up severe stresses in the foam.

ACTION TAKEN (TO BE FILLED OUT BY SERVICE ENGINEERING)

Requested that thedefective dewars be returned to the attention of Bill Mills. Bill also having two replacements shipped to the customer on Friday April 20.

RT BY:

Jack Brower

1—White 2—Yellow 3—Pink 4—Goldenrod 5—Green 6—Buff

USE PENCIL OR SPECIAL PEN ONLY

VARIAN ASSOCIATES
611 HANSEN WAY PALO ALTO

ECL 72

☐ TUBE DIVISION
☐ INST. DIVISION
☐ RADIATION
☒ VACUUM PRODUCTS

Exhibit 8(b) Customer contact report for the initial polystyrene dewar

CONTACT REPORT

ACTION COPY

DATE: 5/2/62

CUSTOMER: BTL

Allentown, Pennsylvania

PERSONS CONTACTED: See below

FIELD REPRESENTATIVE:

REP'S CITY:

PHONE CONTACT ☐ PERSONAL CONTACT ☒

CONTACT INITIATED BY	DISCUSSION HELD AT
☒ VARIAN ASSOCIATES	☐ VARIAN ASSOCIATES
☐ REPRESENTATIVE	☐ REP. OFFICE
☐ CUSTOMER	☒ BTL

ACTION REQUIRED: Follow up on shipment of sieve material and instruction manual for VI-4 system.

BY WHOM: Springfield

DUE DATE:

SALES ENGINEER RESPONSIBLE: Jack Brower

PRODUCT: Tube and semiconductor research

QUANTITY NEEDED:

$ AMOUNT: WHEN WILL HE ORDER: % CHANCE:

COMPETITION: Everyone

SYSTEM DESIGNATION:

REPORT:

The persons contacted at this time were J.C.Meckwood, Tubes, B.C.Syler, W.L.Kaufman, Joseph Seaso and R.M. Jacobs, Semiconductors.

The first thing I have to report is the fact that Mr. Jacobs is very pleased wit the performance of the VI-4 high vacuum evaporator supplied last month. The only complaints that he has are the following:

1. The initial charge of sieve for the VacSorb pumps has not been received.
2. The instruction manual for the system has not been received.
3. The dewars are cracking.

I believe that the VacSorb sieve material and instruction manual were requested from the factory approximately one month ago. As of this date I am under the impression that the two dewars are being shipped in to replace the cracking dewars. A possible explanation for the cracking of the dewars may be the fact that the customer uses the dewars to catch the condensation dripping off the VacSorb pumps. This water may be penetrating the foam material and when liquid nitrogen is poured into the dewar the water may freeze in the pores of the foam and cause cracking.

Mr. Syler has a system in which he evaporates gold. We discussed the leak detector with him and the VI-4 evaporator. I suggested that he try evaporating the gold onto his substrates in the VI-4 system of Mr. Jacobs, in order that he may make an evaluation. He thought that this was a real good idea. His interest

ROUTING	
YELLOW	WHITE
~~[illegible]~~	C. [illegible]
F. [illegible]	D. [illegible]
[illegible]	R. [illegible]
File	
FILE ☐	☐
CUST. ☐	FILE

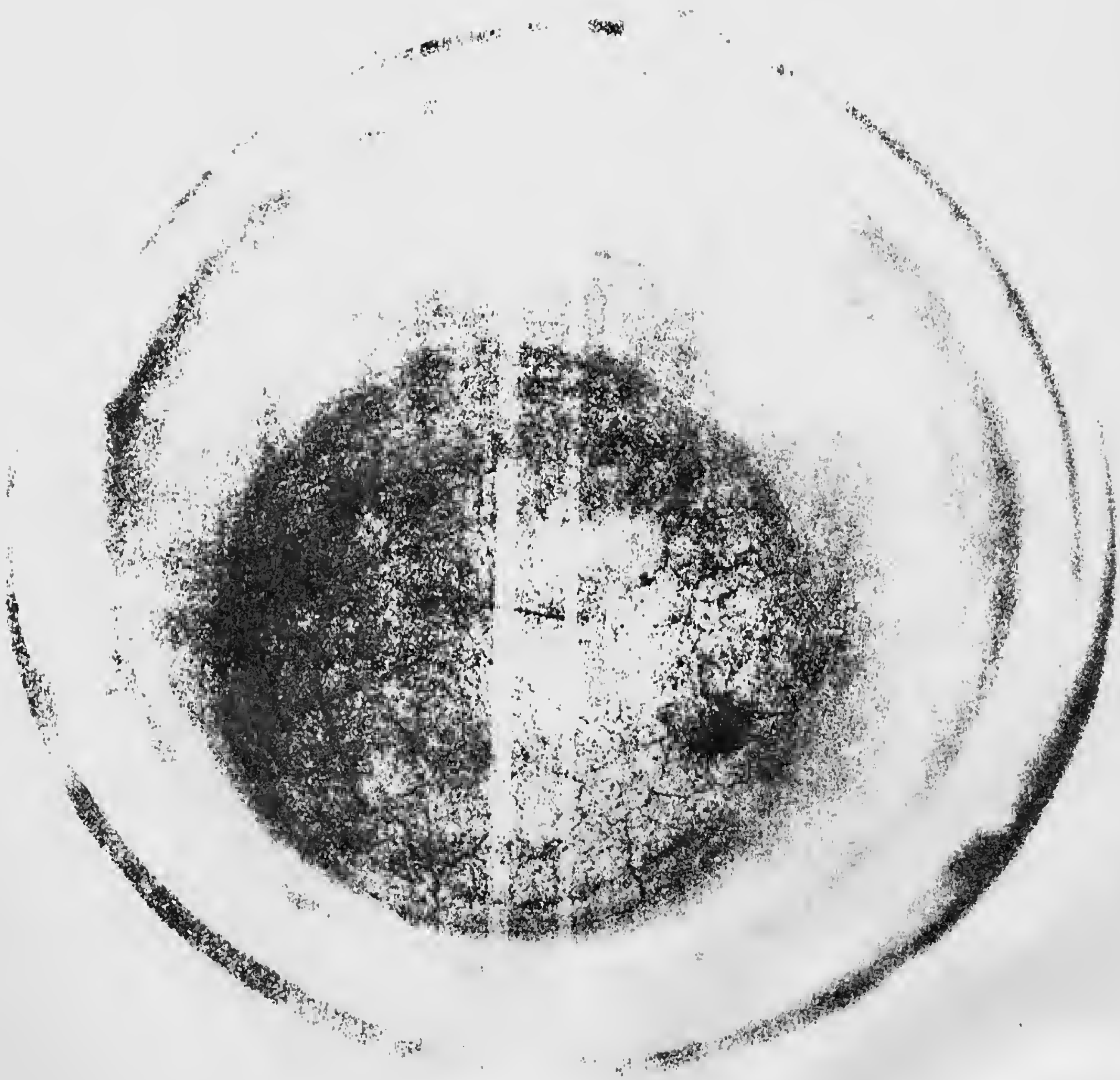


Exhibit 9 Illustration of internal cracks in the initial polystyrene dewar

VARIAN ASSOCIATES (B)

The Redesign of a Liquid Nitrogen Container*

Paul Hait's Role

Paul Hait became involved with the problems of the liquid nitrogen container during the late spring of 1963. The following discussion is essentially what happened in Paul's own words.

Paul's First Visit to Pelafoam

I had several questions which were bothering me. Why are these dewars cracking? Has anyone visited the manufacturer to see how he is making the dewars? What techniques does he use? I just couldn't find anyone who knew exactly how they were being fabricated, and this included Bill Wheeler, John Cape, Maurice Carlson and Stan Swaidek. Not one of them had actually gone up and visited Pelafoam to observe the molding process in detail or to see if the original mold was still being used. So I took a trip to Pelafoam and after observing runs on several dewars (Incidentally, they were using the original mold.) it became obvious to me that they had an arbitrary way of determining the density of the beads. One time they would operate the mold with a steam pressure of approximately 15 psi and another time, at about 22 psi. Consequently the density varied from dewar to dewar which partially explained the random manner in which the dewars developed cracks. I asked George Ackerman, the shop foreman, if I could spend the rest of the day experimenting with the mold. We tried various pressures within the range I mentioned earlier and finally concluded that 19 psi would give us the best bead density.

During the time we were experimenting with various steam pressures we also varied the initial pre-mold heating time for the styrene beads. The pre-mold heating expanded the beads (originally .015 inches to .020 inches in diameter) to approximately 125% to 150% of their original size. This operation affected the final density of the beads in the dewar. Ultimately the best pre-heated bead size was found to be about 133% of the original size. This size and the 19 psi steam pressure was considered the best combination and this gave us a final bead density of 3 lb/ft^3.

I also learned that Pelafoam bought the styrene beads from two different vendors, Dow Chemical Company and Kopper Chemical Company. In fabricating the dewars they would use the beads which happened to be on hand. As it turned out the Kopper beads bonded better than Dow's. They did not stick to the mold and thus produced a bucket with a better surface finish. So the first trip to Pelafoam resulted in (1) establishing an optimum fabrication pressure, (2) determining an optimum pre-mold bead size and (3) selecting a source of beads.

*Based on the problem presented in Varian Associates (A).

Paul's Second Visit to Pelafoam

We had other problems in the fabricating process. While most of the beads were well bonded, we found that when we cut cross sections out of the dewar from top to bottom there seemed to be more air space between beads near the bottom. It thus appeared that the beads were not being uniformly bonded throughout the dewar.

I made a second trip to Pelafoam and after examining the mold again decided that we could probably improve the bonding of all the beads by increasing the number of steam inlet sprue vents which were used to inject steam into the mold (Part A, Exhibit 6). This was done and resulted in a better and more uniform dewar.

Another problem we encountered had to do with the sprue vents leaving little circular ridges on the outside of the dewar. These ridges had to be sanded off before the dewar was painted. I asked Pelafoam to try to do something about this problem too, but they didn't have any ideas. I did notice, however, some styrene work they were doing for the Charles Krug Winery. They were making some multi-colored champagne storing racks out of a mixture of different colored styrene beads (yellow and white or red and white). I noticed that the ridge caused by the sprue vents were effectively camouflaged by the multi-colored nature of the racks. I asked George if I could make up a mixture of black and white beads and fabricate a dewar from them. We made one but the resulting pattern was not as uniform as I would have liked it to be, however, the objectionable ridges were now effectively camouflaged. We decided that if we could develop a satisfactory pattern of beads and thus eliminate the sanding and painting of the dewars this would be a definite savings to Varian. I brought the suggestion back to Varian and tried to sell my boss and other company people on the idea of using a multi-colored dewar. This became a very emotional thing because people were attached to the gray dewar and they didn't like those "little black dots". They thought the mixture of black and white beads would detract from the appearance of our vacuum systems which utilized such buckets. However, Bill Wheeler, my boss, supported me in this idea when I told him what we could save in the manufacturing costs of the dewars. Ultimately the decision was made to go ahead and produce the multi-colored dewars.

Testing the New Buckets at Varian

I brought back some of the dewars which I had made for test purposes and filled them with liquid nitrogen to check for cold spots. Cold spots are just frosty condensation which appears on the outside surface of the dewar if the liquid nitrogen gets to the outside through a small crack. Frost collects and if the level of the liquid nitrogen drops below the small crack the frost melts and the resulting water is trapped around the beads. Then the next time liquid nitrogen is poured into the dewar the water freezes and expands the crack, and before long a large crack develops which results in excessive leaking of the liquid nitrogen.

Thus it appeared that solving the density problem wasn't going to completely solve the leaking problem. Perhaps the liner approach that Stan Swaidek had taken did have merit from the fact that if you could keep the liquid nitrogen within a certain confined region inside the dewar then it wouldn't have a chance to propagate through the styrene. Some of my first thoughts were to use a deep-drawn aluminum liner on the inside of the dewar or to use a layer of aluminum foil. These ideas were tried but they turned out to be more trouble than they were worth.

It was at this point in time that I was home one evening eating dinner and noticed some wax dripping on a kind of net affair that we had on our candle holder. I wondered if paraffin could be used to plug up the cracks in the dewar. I remembered that any particular cross section that I had cut from the interior to the exterior part of the dewar had no less than five small holes per square inch in the bead pattern due to imperfect bonding. My thought was that if I could pour melted paraffin into the dewar it could flow into such holes and perhaps seal the leaks. I proposed the idea to my boss and he took a negative reaction to the suggestion. However, at lunch time one day I bought some paraffin and tried the idea. Fortunately, the temperature at which paraffin is liquid enough to flow in the cracks is still not hot enough to melt the styrene. The first dewar that I chose to demonstrate my new idea on was the "leakiest" dewar which we had in the lab. The dewar had beads anywhere from 1/8 to 1/4 inch in diameter. Previously we would pour liquid nitrogen into this dewar and it would flow out of it just like you were pouring it into a sieve. I filled the dewar with melted paraffin and we could see it dripping out through the cracks. Then I immediately poured the still liquid paraffin out of the dewar, allowed what remained to thoroughly solidify and finally poured liquid nitrogen into the dewar. The dewar did not leak. We still have that bucket and are using it in our labs with no leaking problem. The explanation as to why the paraffin technique worked was that the paraffin formed a complete seal around the bonded beads and the only way it could get out would be by melting it again. We had the other test dewars which had developed cold spots, so we paraffined these and immediately the cold spots were eliminated. Thus, all of the dewars we had used in the earlier tests were now able to hold the liquid nitrogen without developing cold spots. The leaking problem was now solved.

Paul's Third Visit to Pelafoam

Our next problem was to alleviate the cracks in the top of the dewar which developed near the exposed aluminum ring. I spent many sessions with Bill Wheeler trying to convince him that by getting rid of that top ring we could alleviate our final cracking problem. But he insisted that the ring was an aid in pouring the liquid nitrogen out of the dewar. I couldn't disagree with him because this was the case. When you did not have the ring there the liquid nitrogen would tend to adhere to the top edge of the bucket and spill over your fingers as you poured. During a third visit to Pelafoam I had George Ackerman mold a dewar which did not have any ring in it. A small ridge was accidentally left at the top of the dewar and it caused a breakaway effect when I poured the liquid nitrogen out of it. It poured just as though it were going over the aluminum ring. So I tried trimming the top of the dewar to get some definite breakaway lips. After some further pouring experiments, it became obvious that the pouring problem could be solved simply by molding a breakaway lip in the

dewar. We combined this idea with a modified aluminum ring (a ring of aluminum embedded in the styrene with three tab-hooks extending above the styrene) and this effectively solved our pouring problem. See Exhibits 10 and 11.

Labeling the Bucket

Another problem to be solved was the placing of an identifying label on the multi-colored dewar. Two possibilities were, to use some sort of decal, or to mold something directly onto the outer surface of the dewar. Because of the broken-textured surface, molding VA[7] on the dewar would probably not be too distinctive. I accidentally discovered a solution to this problem while putting a new auto-license tab decal on an existing plate. I contacted the outfit who made these decals and asked them if such a decal would stick to a styrene surface. They didn't know so of course the only way to find out was to try it. I put several metalized-mylar decals on a dewar and then cycled the dewar from room temperature to liquid nitrogen temperature. Continued cycling did not appear to have any effect on the adhesion of the decal to the styrene so this method of attaching Varian's name to the dewars was adopted. We actually used three equally spaced "bull's eyes" on each dewar (circular decals with the Varian symbol - Exhibit 10). Three were used so that one would always show when a dewar was used with one of Varian's products.

The new dewar was placed on the market during the summer of 1964, and functioned very well because customer complaints on it virtually disappeared.

Creative Problem Solving

(Author's note: Paul Hait's approach in redesigning the liquid nitrogen container seemed very imaginative, so we asked him how he felt about creativity as related to engineering problem solving. His comments follow:)

"My feeling about creativity is that a person has to relate it to the job he is doing. This means that he has to think and worry about large and small problems and keep them in the back of his mind wherever he goes. You don't want these problems to spoil your personal life, but you must remain alert to what I call 'new exposures'.

"I think of creativity as being something spontaneous. Some people are almost instantly spontaneous, while others have to spend many hours coming up with a problem solution, but it will be just as creative as the other. Some people just pursue a creative idea a little more than others, or some people just say, 'Well, I haven't got it. Where do you get these ideas?' Many creative ideas come about due to the fact that you have recognized there is a problem. People who recognize problems are generally more creative than those who don't because the latter are not trying to be creative.

"The company I work for is seeking out creativity, and this is what they are paying you for. The person who can really solve problems is the one who is going to get ahead faster."

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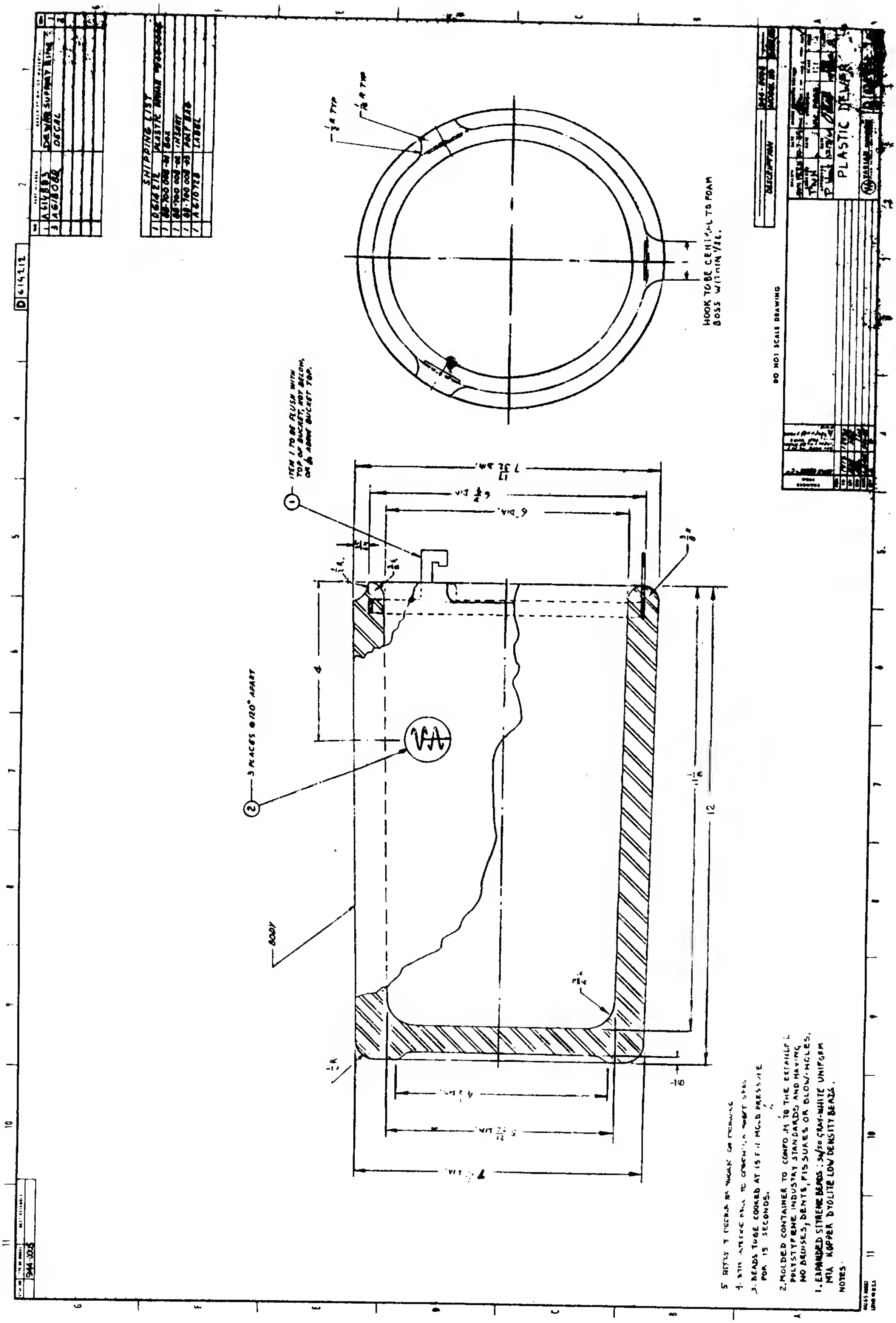
[7] Abbreviation for Varian Associates.

PART B - CLASS DISCUSSION QUESTIONS

1. How did Paul Hait's approach to redesigning the liquid nitrogen container differ from the approaches previously discussed (Part A)?

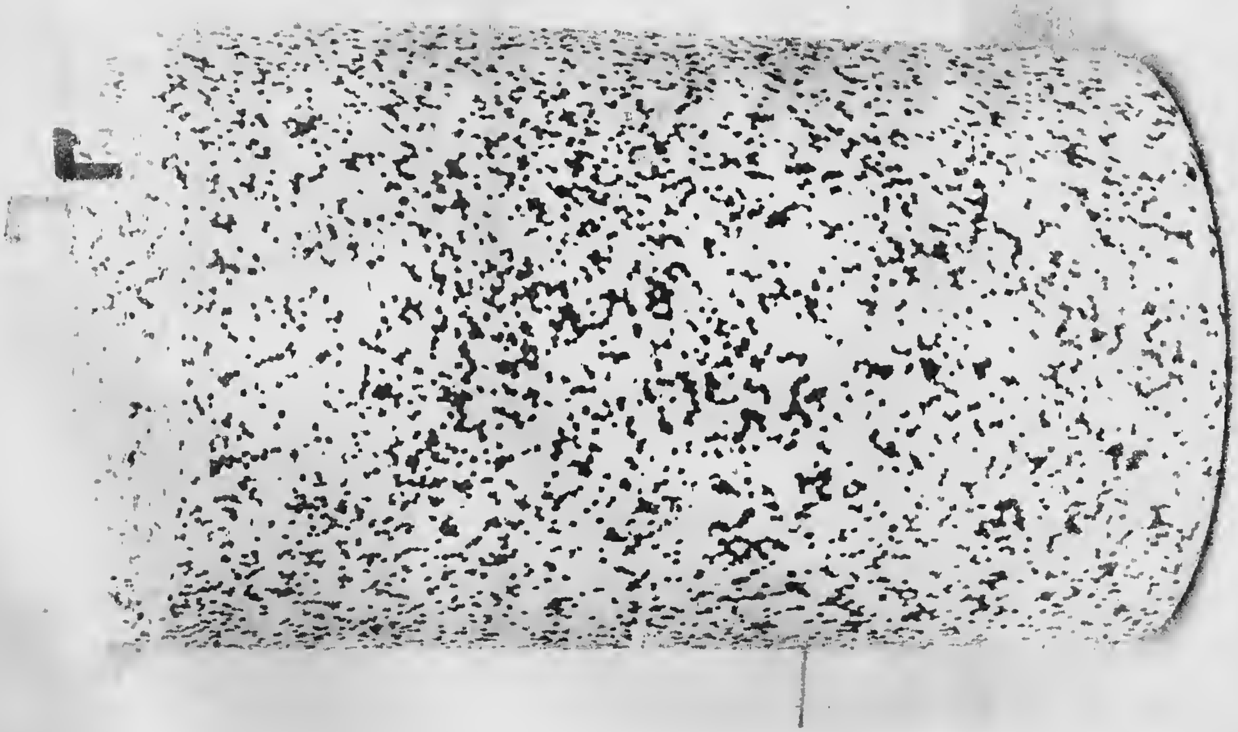
2. If you were redesigning the liquid nitrogen container, what would you do that would differ from what Paul Hait did?

3. Discuss Paul Hait's approach to creative problem solving. Do you agree with it? What is your opinion of creativity and the creative person?

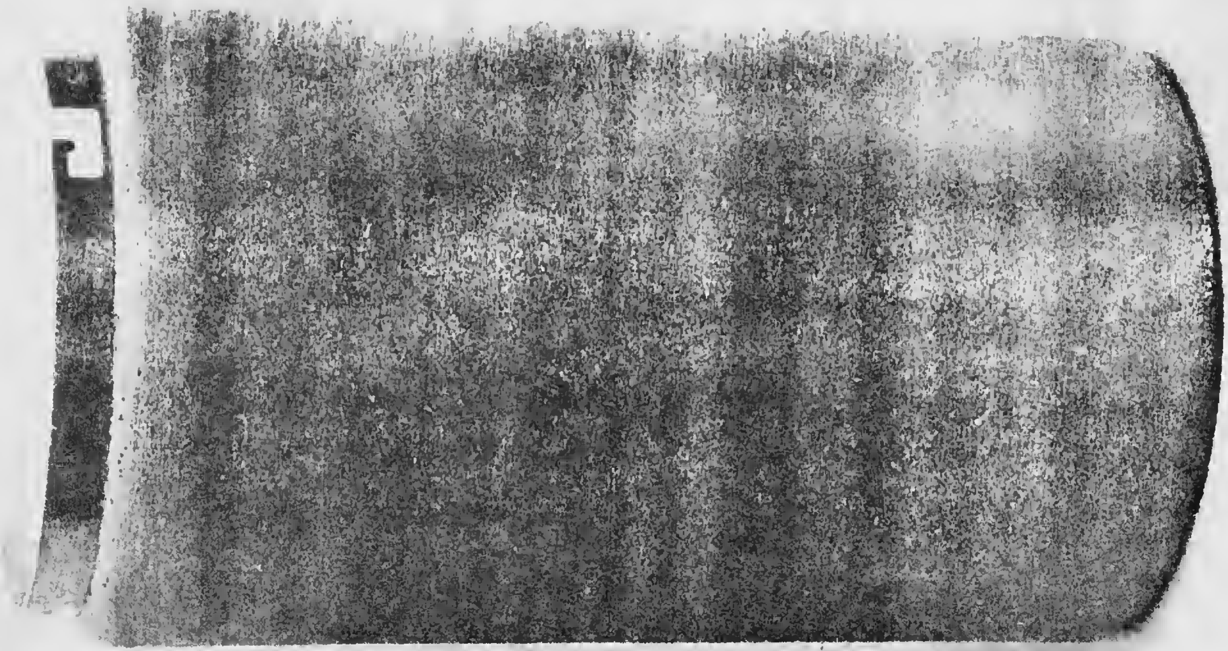


The Redesigned Liquid Nitrogen Container

Exhibit 10



(a) The redesigned dewar



(b) The dewar before redesign

Exhibit 11

VARIAN ASSOCIATES (C)

The Redesign of a Liquid Nitrogen Container*

Conclusion and Future Prospects

The liquid nitrogen container is now a very reliable item. Warranty replacement costs have been reduced to almost insignificant numbers. Most of the replacement costs have involved the replacing of old dewars with the new mixed bead variety.

The new dewar is a very marketable item. It is the only styrene variety on the market at the present time and its price is lower than any other commerically available dewar. Other dewars that are sold by competitors are either made of fiberglass or are similar to the original Hoffman model. They generally are two or three times more expensive than the one sold by Varian.

The new Varian dewar sells for about $26 and sales have averaged about 1000 per year since it went on the market in the summer of 1964. It is now a money making item. A cost reduction chart comparing the old dewar (pre Paul Hait) to the new one is shown in Exhibit 12.

At the present time Varian is satisfied with the styrene dewar and will probably not invest any more money in improving it per se. As Paul Hait says, "When you're producing a reliable product at a reasonable cost and selling it at an appreciable markup, and making money on it, you can't justify going back into this $26 item and putting in a lot more engineering time. It's a fairly simple minded thing, and once you can get it to work, it doesn't make too much sense tearing into it again and basically trying to weed out all the minute problems."

Looking to the future, Varian has just designed and marketed a new stainless steel dewar. This dewar uses vacuum insulation instead of styrene and can be permanently mounted on a VacSorb Pump. This allows the VacSorb Pump to be more easily adapted to some form of automated operation, since you need not remove the stainless steel dewar when it is necessary to bake out the VacSorb[8]. With the styrene dewar you would have to remove the pump for bake out. Then you would have to wait for the VacSorb to cool down before putting the dewar back on. The reason being that if you put the styrene dewar on the hot VacSorb without pouring any liquid nitrogen into it, the radiant heat from the pump will cause some melting of the interior paraffin coating. If this were repeated several times it would cause erosion of the dewar at the spots where the paraffin has melted away. This has actually occurred in the field.

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*Based on the problem presented in Varian Associates (A) and (B).

[8] See Exhibit 4, Part A.

However, even with the new stainless steel dewar there still should be a good market potential for the styrene variety. Paul Hait believes that Varian should sell about 1000 styrene dewars per year for some time to come.

The recognition of the overall problem was the key factor in the successful redesign of the liquid nitrogen container.

To quote Paul Hait, "Even though you're creative your creativity doesn't mean very much unless you're able to recognize a problem that needs solving and then proceed in some methodical way to solve it. If you always want to generate a random pattern of solutions you generally don't solve your problem. Many of the approaches that were taken on the liquid nitrogen container were random solutions. They weren't 'Let's start out with the facts and try to go through every step and look at each one.' Once you do this and the total picture is seen, then the solutions become quite easy."

PART C - CLASS DISCUSSION QUESTIONS

1. Do you think Varian was justified in spending their time and money in the redesign of the styrene dewar?

2. What was the real problem here? Was it the liquid nitrogen container or was it something else?

3. How does an engineer go about recognizing problems that need to be solved?

EXHIBIT 12

Cost Comparison

Liquid Nitrogen Containers

Old Dewar		New Dewar	
Styrene Container	4.50	Styrene Container	4.30
Aluminum Ring	1.80	Aluminum Ring	.65
Paint	.20	Varian Decal	.06
Polyethylene Liner	.50	Waxing	.10
Styrene Liner Holder	.30	Warranty / Overhead	1.50
Sanding (Labor)	.33	Packaging	.20
Masking (Labor)	.20		
Painting (Labor)	.20		
Packaging (Labor)	.20		
Warranty / Overhead	5.00		
	13.23		6.81

Selling Price $26.00

Dewar Made in Lots of 100

Sales Per Year 1000

$6000 to $10,000 Per Year
Saved in Manufacturing New Dewar